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Effect of Exercise on Bubble Activity during Diving

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Exercise is intrinsic to military and commercial diving, and exercise may either increase or decrease the risk of decompression sickness (DCS) after diving. Vann and Thalmann (1) explained the relation between exercise, diving, and the risk of DCS using the parameters of: exercise intensity, exercise duration, and the phase of diving during which exercise is performed. Before diving, intense, vigorous or ballistic exercise which induces muscular soreness may also create microscopic intramuscular gas nuclei which increase the risk of DCS. During diving, the increased metabolic rate of exercise can enhance the rate of inert gas absorption, rapidly causing tissue supersaturation and subsequently increasing the risk of DCS (2-4). After diving, vigorous exercise or forceful straining which involve the Valsalva manoeuver is associated with cavitation, bubble formation, and the coalescence of micro-bubbles all of which increase the risk of DCS (1,2,4,5). Thus, although exercise is integral to diving, exercising before, during, and after diving, for several different reasons, may be associated with an increased risk of DCS. Exercising appropriately during decompression, however, may facilitate inert gas elimination and reduce the risk of DCS. While this hypothesis originated with Boycott, Damant and Haldane (6) in 1908, several investigators studying both divers and astronauts have since suggested that exercise may facilitate inert gas elimination and therefore reduce the risk of DCS after diving or during spaceflight (1,2,4,7-11)). Rather than study DCS symptomatically, bubble activity may be measured directly using Doppler ultrasonic monitoring for venous gas emboli (VGE) (12). The purpose of this investigation was to test the hypothesis that bubble activity can be reduced by performing moderate intermittent exercise during decompression.

MATERIALS AND METHODS

This investigation was approved by the Human Research Ethics Committee of the Defence and Civil Institute of Environmental Medicine (DCIEM), Department of National Defence, Canada, and conducted in the water-filled portion of the Diving Research Facility. Thirty-nine healthy males, 11 Canadian military divers and 28 commercial diving students, voluntarily performed a total of 100 simulated dives in the hyperbaric chamber during the study. Each experimental dive (Fig. 1) was to a pressure of 450 kPa equivalent to 45 metres of seawater (msw) for 30 min followed by a 55 minute staged decompression according to the DCIEM Standard Air Diving Table (13). Some divers elected to make a 300 kPa (30 msw), 12 min no-decompression "work-up dive" no less than two days before their first experimental dive. A minimum of five days was required between the beginning of any two consecutive dives for all subjects. Subjects were assigned to one of four trials:

inactive during both the bottom period and during the decompression – (*I/I*),
inactive during the bottom and active during decompression – (*I/A*),
active during the bottom and inactive during decompression – (*A/I*), and
active during the bottom and active during decompression – (*A/A*).

Active subjects performed five minutes of moderate arm or leg exercise beginning at minute 5, 15, and 25 of the compression, and/or minute 7, 15, 25, 35, and 45 of the decompression (Fig. 1). Each exercise period was followed by five minutes sitting at rest. Leg exercise was performed on submersible electrically braked bicycle ergometers (Warren E. Collins, Braintree, Ma.) installed in the dive chamber. The ergometers were waterproofed

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in the manner described by Thalmann et al (14). Arm exercise was performed on an specially constructed paddle ergometer or by lifting light weights. The intensity of both the arm and leg exercise was maintained at approximately 50% of each subject's previously determined arm or leg VO_2 max by monitoring heart rate (7,15,16) via an unorthodox precordial electrocardiograph lead obtained by using three chest electrodes hard wired through the data acquisition unit of the dive chamber and connected to standard clinical electrocardiograph recorders equipped with digital cardiotachometers (MultiCare Model 304, Rigel Research Ltd., Morden, Surrey, England). No attempt was made to correct the heart rates for the effects of immersion or increased PO_2.

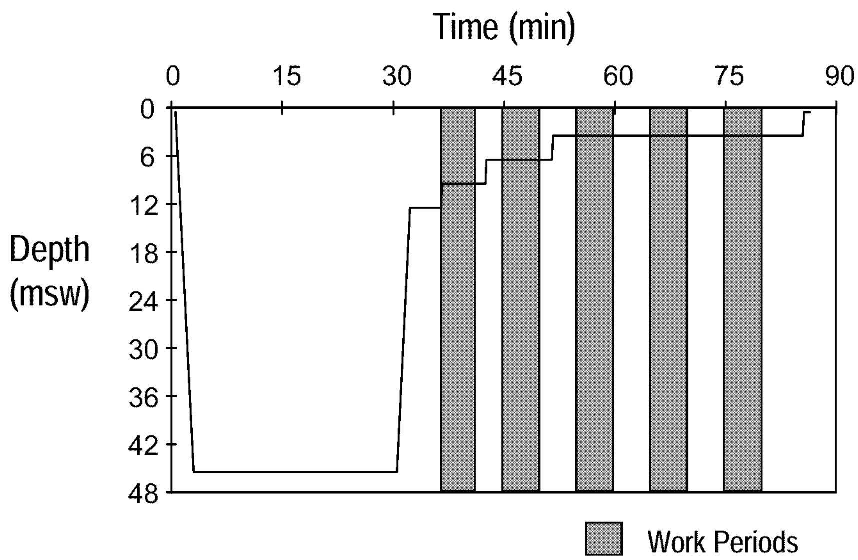

Figure 1. Dive profile used (45 msw for 30 minutes) showing activity periods during decompression stops.

VGE monitoring was conducted at approximately 21, 61, 100, and 147 minutes after the decompression ended by experienced Doppler technicians using ultrasonic bubble detectors (TSI DBM 9008, Techno Scientific Inc. Woodbridge, Ont.). Each subject's precordium was monitored with the subject standing at rest. Both the left and right subclavian veins were also monitored and assessed at rest. Rather than treating the left and right subclavian scores of each subject independently, the highest of the two scores was used as the most meaningful indicator of VGE status and DCS risk. The auditory output from the bubble detector was scored manually, using the Kisman-Masurel (KM) code and simultaneously recorded on audiocassettes. The KM code was converted to a single bubble grade using a 12 point ordinal bubble grade from 0 to IV (0,1-, 1,1+... IV-, IV, IV+). The bubble grade at rest was subsequently used to calculate the Kisman integrated severity score (KISS) according to the following formula (17,18).

$$KISS = \frac{100}{4^{\alpha}(t_4 - t_1)} \sum_{i=1}^{3} \frac{(t_{i+1} - t_i)(d_{i+1}^{\alpha} + d_i^{\alpha})}{2}$$

where: $\alpha = 3$ (α accounts for the fact that the bubble grade is not a linear measure of bubble quantity)
t = time of observation in minutes after reaching the surface and
d = Doppler grade (0 to IV) observed at time t.

The KISS is an index derived from integrating the bubble scores over the observation period; hence it takes into account not only the bubble grade but also the time distribution of observed VGE. It is related to the volume of released gas and gives a better representation of overall VGE activity than the maximum bubble grade observed after a dive.

In addition to the KISS analysis, the precordial bubble grades observed in the precordium were also converted to bubble count estimates (BCE) (bubbles/cm^2) using a scale (Table 1) developed by Eftedal *et al.* (19,20). The BCE was derived from an analysis of simultaneous transesophageal echocardiography and Doppler monitoring in pigs.

Table 1. Correspondence between KM Bubble Grades and Bubble Count Estimates (bubbles/cm^2)

K.-M. grade	0	I-	I	I+	II-	II	II+	III-	III	III+	IV-	IV
Bubbles/cm^2	0	0.01	0.05	0.1	0.15	0.2	0.3	0.5	1	2	5	10

A preliminary analysis of these data revealed that the effects of arm and leg exercise were quite similar and, in fact, not significantly different from each other (p>0.05). Consequently, these data were pooled and activity (*A*) data include both arm and leg exercise.

Subject populations in the four groups were as follows: *I/I* and *I/A* groups – 12 subjects each; *A/I* and *A/A* groups – 13 subjects each. Although some subjects did more than one dive in each group, only the first dive done by a subject was selected for analysis. Furthermore, when a subject participated in both the groups being compared, the results of only one experiment were selected (i.e., if a subject initially participated in group *I/I* and later in group *I/A*, only the data from the *I/I* dive were used). Finally, subjects in *I/I* were different from those assigned to *I/A* and those in *A/I* were different from those assigned to *A/A*.

Both the KISS and BCE values can be treated as scores or indices and their values can be considered non-parametric. The appropriate test statistic of such data between independent groups is the Mann-Whitney U or rank sum test (21). This test is one of the most powerful non-parametric tests to test whether or not two independent groups have been drawn from the same population. Essentially this test determines whether the median scores between the groups is statistically significant, in this case at $p < 0.05$.

Based on the hypothesis that physical activity during decompression reduces bubble activity, the following groups were tested: *I/I* vs. *I/A* and *A/I* vs. *A/A,* with the expectation that bubble activity should be higher in the former group of each pair.

RESULTS:

Figure 2 shows the comparison between the means of the KISS values for the *I/I* and *I/A* groups and the *A/I* and *A/A* groups. The median precordial and subclavian KISS's for the divers were consistently significantly lower for *I/A* compared to *I/I*. For the *A/I* vs. *A/A* trials, the resting precordial KISS was significantly lower for the *A/A* condition. Although there was a decrease for the subclavian veins for the *A/A* trials, the decrease was not significant at the 0.05 level.

Figure 3 shows a comparison of the mean BCE observed at times 21, 61, 200 and 147 minutes after the end of decompression. The BCE can be considered to be a "snapshot" of VGE activity at discrete times after a dive. The median BCE's for trial *I/A* at minutes 61 and 100 at rest were significantly lower compared to trial *I/I*. The median BCE's for trial *A/A* at rest at minutes 100 and 147 were significantly lower compared to trial *A/I*.

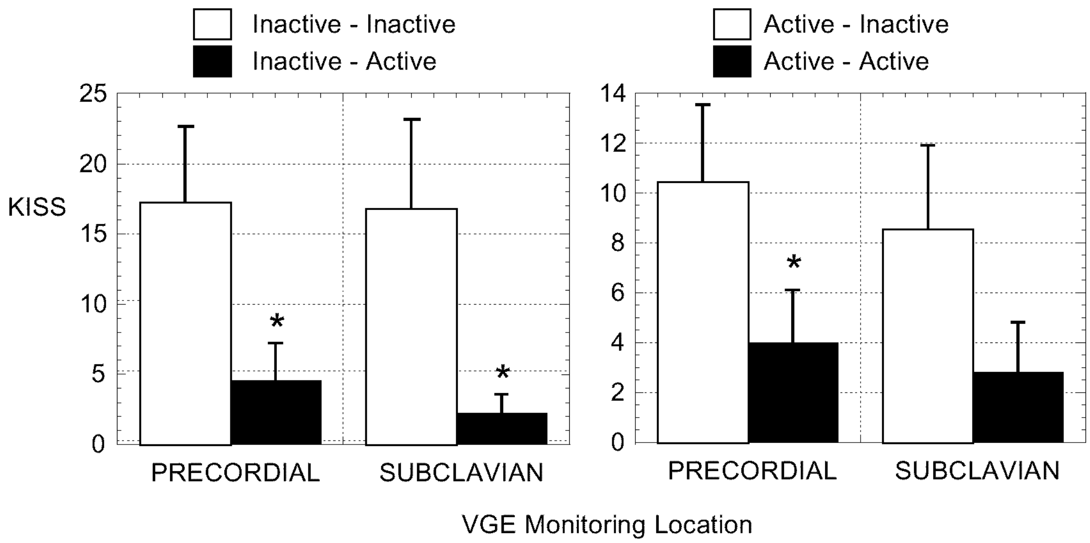

Figure 2. Mean and standard error for Kisman Integrated Severity Scores in the precordium and subclavian veins for the diver at rest.

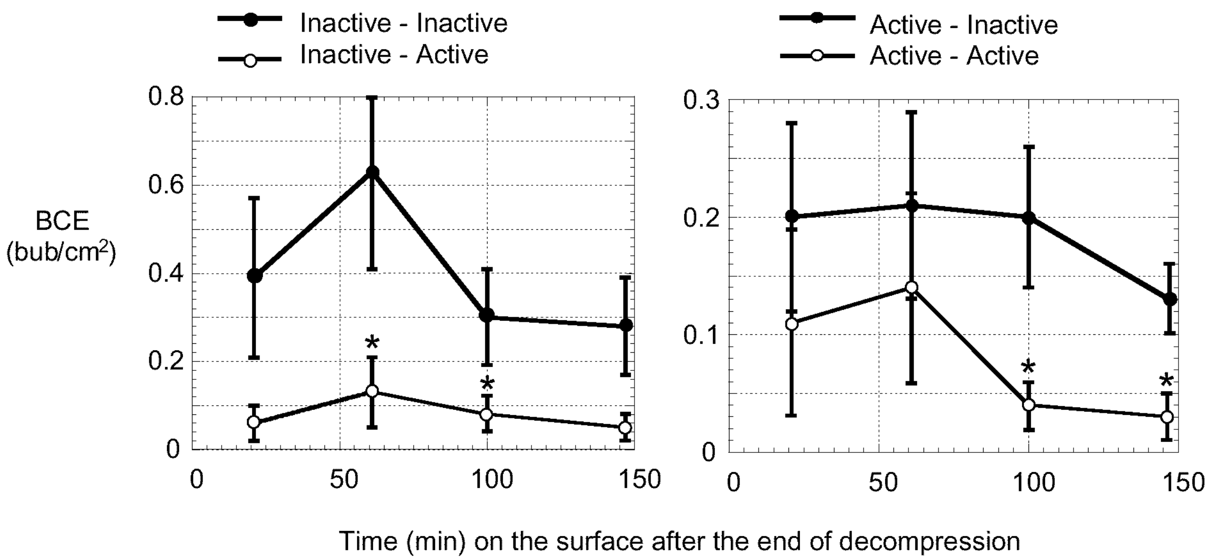

Figure 3. Bubble Count Estimates (bubbles/cm2) at 21, 61, 100 and 147 minutes after decompression.

DISCUSSION:

In all group comparisons of KISS and BCE, scores tended to be higher with inactive compared to active decompression, and these differences were significant in 3 of the 4 KISS comparisons and in half of the BCE comparisons. On the strength of the trends exhibited by these observations, it would seem reasonable that statistical significance would be achieved with greater numbers of subjects, and so it would be logical to conclude support of the hypothesis that physical activity during decompression decreases Doppler-monitored bubble activity. This suggests that mild exercise during decompression enhances inert gas elimination and, by extension, may reduce the risk of decompression sickness and enhance diver safety. It has not determined whether or not mild exercise may enhance inert gas elimination to the point of reducing the times required for inactive decompressions.

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